Shallow Water Mid-frequency Research and SW06

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LONG-TERM GOALS

To understand mid-frequency (1-10 kHz) acoustics in shallow waters through measurements and modeling, including propagation, reflection, and forward- and backscatter, as well as reverberation. The top-level goals of this effort are to understand the important environmental processes that impact mid-frequency sonar performances in shallow water environments, and to develop means to efficiently collect those environmental data.

OBJECTIVES

The LEAR (Littoral Environmental Acoustics Research) field experiment as part of Shallow Water 2006 (SW06) project yielded abundant data sets carefully collected for the purpose of investigating mid-frequency (1-10 kHz) acoustics interacting with environments. Both acoustic data and relevant environmental data were measured contemporaneously to facilitate close model/data comparison. During FY09, research has been concentrated in the areas of data analysis and documentation of results. An important underlining emphasis going forward is to define what is needed to conduct a 6.1 reverberation experiment at the mid-frequency where environmental processes relevant to the reverberation modeling are also measured. The objectives are:

1. Analyze mid-frequency propagation data in shallow water in the presence of small ambient internal waves. Specifically, study the mean acoustic intensity field and its fluctuations (scintillation index). The significance of the work is that little has been done on this topic in shallow water environments. The effort is to support application of mid-frequency sonar in shallow water environments.
2. Analyze sediment sound speed data from in situ measurements using the SAMS (Sediment Acoustics Measurement Systems). The goal is to extend the SAMS's capability to lower frequencies in order to measure sediment sound speed dispersion as low as 700 Hz.
3. Short range (500 – 1000 m) propagation through internal waves – whether acoustic interaction with internal waves can be modeled using deterministic measurements of internal waves.
4. Modeling bottom ripple fields as a non-Gaussian process and studying its role in "clutter."
5. Development of an efficient modeling capability based on PE (Parabolic Equation) to model mid-frequency reverberation.

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APPROACH

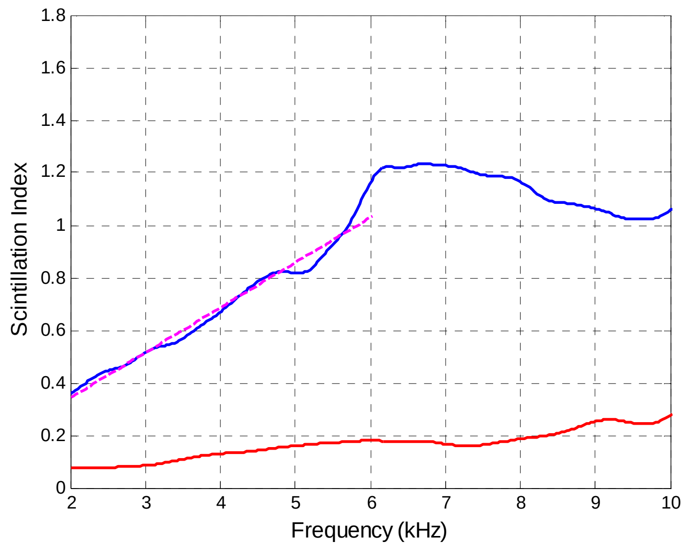
Because mid-frequency data in shallow water are limited, we continue to base our analysis and development of models on data sets collected in SW06 off the New Jersey coast, where both acoustics and environmental data are available. This is crucial for achieving the goal of quantitative model/data comparisons of sound fields interacting with bottom, surface, and the water column. Based on work from the previous two years, we made oceanographic models to predict sound propagation under the influence of internal tides. In this approach, environmental measurements from the SAMS and IMP2 are used to provide geo-acoustic inputs. Another important area is the study of sound intensity fluctuation, where we identified a single arrival from other arrivals to quantitatively analyze the scintillation index. We also approached the mid-frequency problems theoretically in two topics: one is the modeling sediment ripple fields as a non-Gaussian process that can be a "clutter" mechanism; the other is formulating reverberation in a range-dependent environment by the combination of using the PE as the two-way propagator and perturbation theory for backscatter.

WORK COMPLETED

1. Analysis of sound scattering by internal solitary waves with (collaboration with Henyey, Williams, and Yang).
2. Modeling non-Gaussian sediment ripple fields (collaboration with Henyey, Hefner, and Traykovski).
3. Mid-frequency intensity scintillation index analysis (collaboration with Rouseff, Henyey, and Yang).
4. Formulation and initial numerical implementation of Monte Carlo reverberation model based on PE and perturbation theory.

RESULTS

1. Scintillation Index. The figure below shows the measured scintillation index of a single arrival at 1 km range going through two upper-turning points as a function of frequency (blue). The red curve is scintillation of a bottom bounce arrival as a reference. The pink line is an estimate of the slope of the scintillation index as a function of frequency. The trend demonstrates that the scintillation index goes from under saturation, to over saturation (around 6 kHz) and saturation (9-10 kHz). It was previously anticipated that saturation would not happen at such short range. This result provides quantitative explanation to why match-field processing works better at low-frequency, where scintillation is low, but is problematic with increasing frequency. A paper on this topic is in preparation, and modeling the observed scintillation index is in next year's research schedule.



2. Sandy sediment ripples impact sonar performance in coastal waters through Bragg scattering. Observations from data suggest that sandy ripple elevation relative to the mean seafloor as a function of the horizontal coordinates is not Gaussian distributed; specifically, peak amplitude fading over space associated with a random Gaussian process is largely absent. Such a non-Gaussian nature has implications for modeling acoustic scattering from sediments and might be a clutter mechanism. An algorithm is developed to generate ripple fields with a given power spectrum; these fields have non-Gaussian statistics and are visually consistent with data. Higher-order statistics of these ripple fields and their implications for sonar detection are discussed and a recent publication.

3. Nonlinear internal waves on the continental shelf depress the thermocline and thicken the surface mixed layer with consequent effect on acoustic propagation. After the waves have passed, it may take several hours for the thermocline to rise to its pre-wave level. The slow rising thermocline caused by the internal tide trailing the waves is relevant to acoustics because it may last for several hours while nonlinear internal waves may transect a given acoustic track for only a small fraction of the tidal period. To examine the effect of the rising thermocline, oceanographic and acoustic data collected during the Shallow Water 2006 Experiment are analyzed. Mid-frequency acoustic data taken for several hours at both fixed range (550 m) and along a tow track (0.1—8.1 km) are studied. At the fixed range, the rising thermocline is shown to change acoustic intensity by 5 dB. Along the tow track, the transmission loss changes 2 dB for a source-receiver pair that straddles the thermocline. The effects on acoustic signals are shown to be observable, significant, and predictable. The above results are reported in a paper to IEEE Journal of Oceanic Engineering.

4. A new model of reverberation capable of dealing with range-dependent environment is developed. The parabolic equation method is used to handle the two-way propagation, and first order perturbation theory is used to handle the backscatter. Because the calculation time is independent of the number of realizations, this method is much faster numerically than any models available. Another advantage is of this method is that it can easily handle complications such as internal waves and swells. We plan to use this new model in the next year to address a number of reverberation issues, especially how clutter is forms.

IMPACT/APPLICATIONS

We anticipate impacts in the following areas: first, the work on scintillation index will help open further research of sound wave propagation in shallow water as a problem of wave propagation in random media, linking shallow water research to that in the deep ocean, both managed by ONR's acoustics program. Second, the work on non-Gaussian ripples will provide a way to model clutter based on this particular physical model. Third, the new reverberation model makes it possible to simulate a large number of shallow water reverberation problems. On the very top of our agenda, we would use the model to investigate the following hypothesis: shallow water clutter is due to the combination of forward scatter that diverts sound to higher grazing angles, and backscatter from these high angle incident energy.

RELATED PROJECTS

ONR reverberation workshop series (Thorsos and Perkins)

PUBLICATIONS

1. Henyey F., K Williams, J. Yang, and D. Tang, “Simultaneous nearby measurements of acoustic propagation and high-resolution sound speed structure containing internal waves,” *IEEE J. Oceanic Engineering* (under reviewed).
2. Yang, J., D. Rouseff, D. Tang, and F. S. Henyey, “Effect of the internal tide on acoustic transmission loss at mid-frequencies”, *IEEE J. Oceanic Engineering* (accepted).
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4. Tang, D. F. S. Henyey, B. T. Hefner and P. A. Traykovski, “Simulating Realistic-Looking Sediment Ripple Fields,” *IEEE J. Oceanic Engineering* (accepted 2009, available online).
5. Wang, C. and D. Tang, “Seafloor Roughness Measurement by Laser Line Scanning and Conductivity Probe at SW06 Experiment Site,” (accepted 2009, available online).
6. Jackson, D. R., M. D. Richardson, K. L. Williams, A. P. Lyons, C. D. Jones, K. B. Briggs, and D. Tang, “Acoustic Observation of the Time Dependence of the Roughness of Sandy Seafloors,” *IEEE J. Oceanic Engineering* (accepted 2009, available online).
7. Briggs, K. B., A. H. Reed, D. R. Jackson, and D. Tang, “Fine-scale volume heterogeneity in storm-generated stratigraphy in sandy sediment off Fort Walton Beach, Florida, USA,” *IEEE J. Oceanic Engineering* (accepted 2009).
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10. Rouseff, D. D. Tang, K. L. Williams and Z. Wang, “Mid-frequency sound propagation through internal waves at short range with synoptic oceanographic observations,” *J. Acoust. Soc. Am.* ***124*** EL73 (2008).

11. Yang, J., D. Tang, and K. L. Williams, “Direct measurement of sediment sound speed using SAMS in SW06,” *J. Acoust. Soc. Am.* **124**, EL116 (2008).

12. Lynch, J. and D. Tang, “Overview of Shallow Water 2006 *JASA EL* Special Issue Papers,”J. Acoust. Soc. Am. **124**, EL63 (2008).

13. Tang, D. J. N. Moum, J. F. Lynch, P. Abbot, R. Chapman, P. H. Dahl, T. F. Duda, G. Gawarkiewicz, S. Glenn, J. A. Goff, H. Graber, J. Kemp, A. Maffei, J. D. Nash, and A. Newhall, “Shallow Water ’06: A Joint Acoustic Propagation/Nonlinear Internal Wave Physics Experiment,” *Oceanography* Vol. 20, No. 4 pp156-167 (2007)

14. Wang, C. and D. Tang, “Estimating shell fragment distribution on the seafloor from images of laser scans,” (Submitted to *Ocean Engineering*).